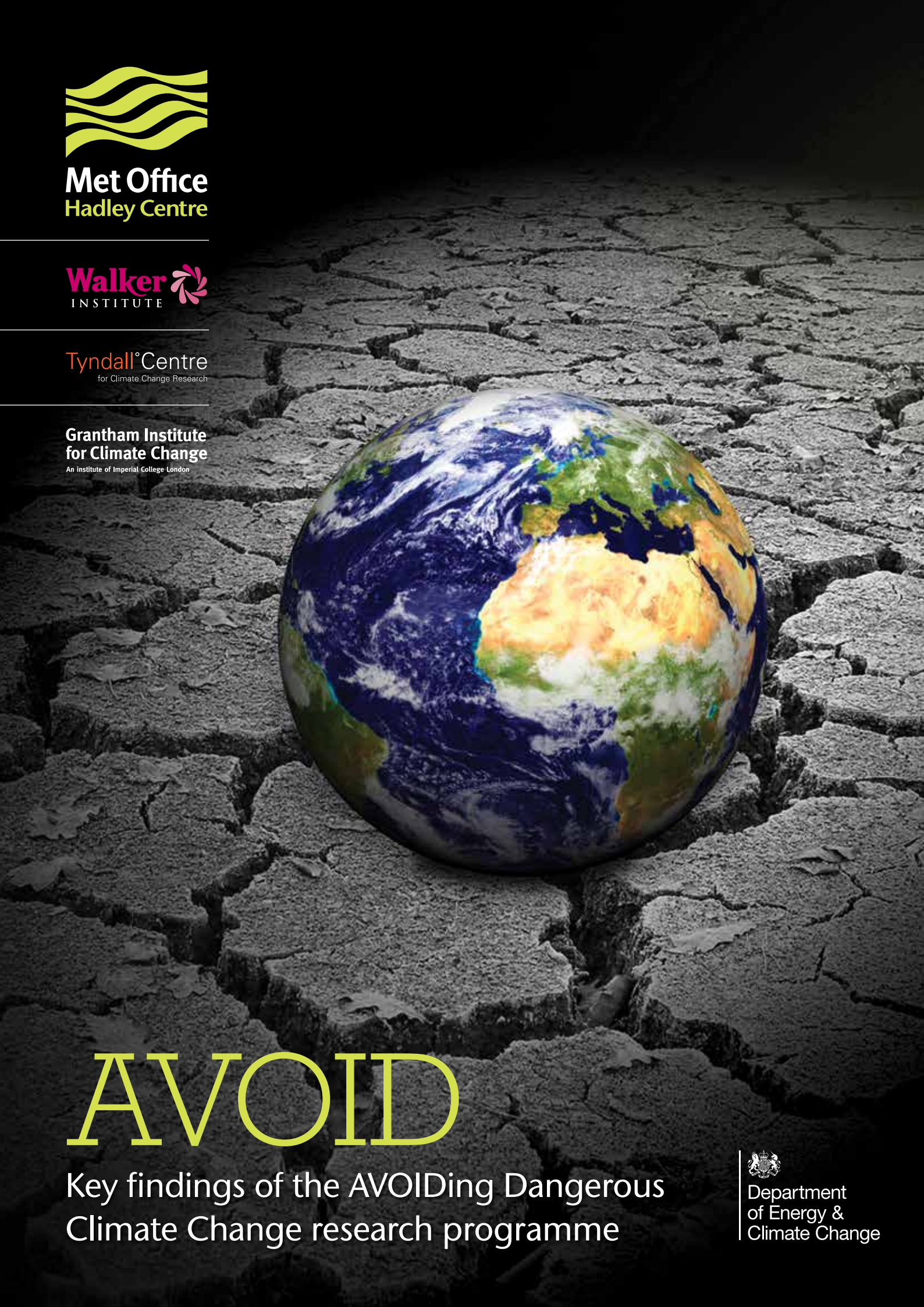
Met Office
Hadley Centre

Walker
INSTITUTE

Tyndall Centre
for Climate Change Research

Grantham Institute
for Climate Change
An institute of Imperial College London

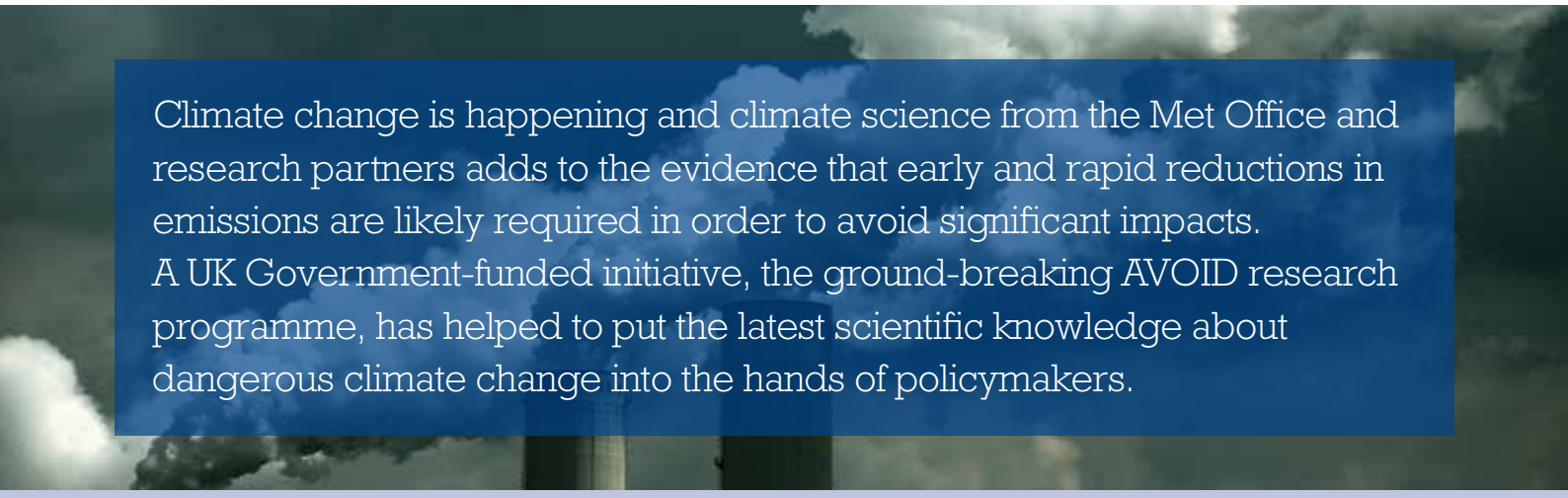


AVOID

Key findings of the AVOIDing Dangerous Climate Change research programme

Department
of Energy &
Climate Change

What is AVOID?



Climate change is happening and climate science from the Met Office and research partners adds to the evidence that early and rapid reductions in emissions are likely required in order to avoid significant impacts. A UK Government-funded initiative, the ground-breaking AVOID research programme, has helped to put the latest scientific knowledge about dangerous climate change into the hands of policymakers.

The AVOID programme tackled three big questions:

- What are the characteristics of dangerous climate change?
- What greenhouse gas emissions pathways will avoid dangerous climate change?
- What is the feasibility of such pathways?

Who is involved?

Funded by UK Government, AVOID saw scientists at the Met Office Hadley Centre working alongside experts in three other leading climate organisations: the Walker Institute at the University of Reading, Grantham Institute for Climate Change at Imperial College and Tyndall Centre through the University of East Anglia. Many other national and international collaborators contributed to this vital work through the AVOID network.

This brochure summarises some of the key findings of the AVOID programme. These include highlighting the large magnitude of potential impacts in a warming world and new evidence of the fraction of damage that could be avoided or delayed by mitigation.

The information in this brochure is a summary of the results from the AVOIDing Dangerous Climate Change research programme. For further information visit: www.avoid.uk.net

What is 'dangerous' climate change?

Climate science can help policymakers to determine what constitutes potentially 'dangerous' climate change. Ultimately, the impacts will be experienced locally by people, habitats and infrastructure, for which varying values apply. The AVOID programme provided evidence to inform policy.

This concept of 'dangerous' climate change is a key aspect of Article 2 of the United Nations Framework Convention on Climate Change (UNFCCC) which states:

> "The ultimate objective of this Convention and any related legal instruments that the Conference of the Parties may adopt is to achieve, in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a timeframe sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner."

The significance of imminent dangers to the climate system (e.g. loss of major ice-sheets, rapid changes to ocean circulation, and dieback of tropical forests) and the consequences for human society (e.g. food production, water availability and energy demand) must be considered. Impacts are also associated with extreme weather events, which are already changing as the climate warms.

When it comes to setting targets in international negotiations, 'dangerous' climate change is expressed in terms of limiting global average temperature rise to an agreed-upon maximum threshold. At present, 2 °C above the pre-industrial level is the target adopted by the UNFCCC. In the UK, the Committee on Climate Change advises on a climate objective that gives approximately a 50% chance of limiting warming to 2 °C above pre-industrial levels and reduces the probability of reaching 4 °C to very low levels.

What are the dangers to the

The AVOID programme assessed the research into rapid or irreversible changes to the climate system that has been conducted since the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC 2007). Some of the results are summarised here, together with other results from AVOID work on sea-level rise and acidification of the oceans.

Ocean circulation

The large-scale ocean overturning circulation in the North Atlantic transports warm water northwards. It gives areas such as the UK a warmer and wetter climate than they would otherwise have. Studies since IPCC 2007 found that this circulation is highly variable. There is also new evidence that the circulation remains sensitive to the effects of greenhouse gas emissions and that it may also be more susceptible to aerosols than previously thought.

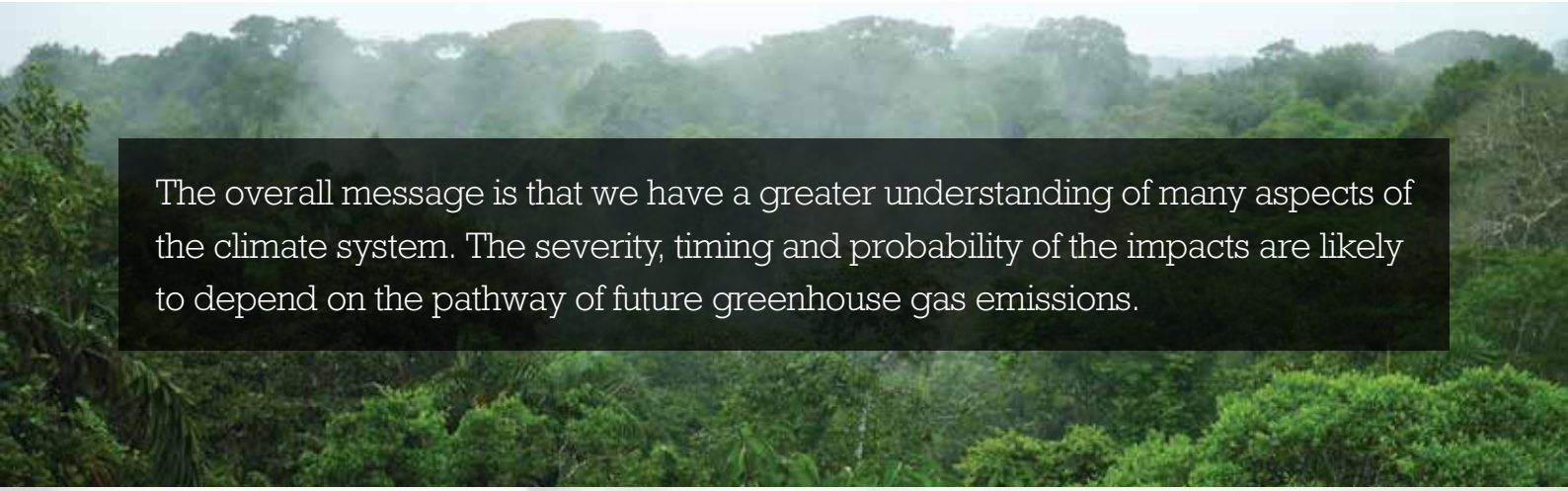
Sea-level rise and melting of the great ice-sheets

Sea-level rise is caused primarily by thermal expansion of seawater and melting of ice on land. The regional consequences include: coastal flooding, erosion of the coastline and salination of freshwater. While it's not possible to rule out increases in sea level in excess of 1 metre by the end of the century, it is more likely to be less than this. The biggest question mark over sea-level rise projections is in quantifying the contribution from melting of the great ice-sheets. Increasing loss of ice from the Antarctic and Greenland ice-sheets has been reported over recent decades, but there is still large uncertainty in modelling ice-sheet dynamics. AVOID studies found that while sea-level rise may be reversible theoretically, it is projected to continue for centuries, even under the Copenhagen Accord emissions reduction pledges. However, mitigation can reduce the rate of 21st century sea-level rise.

Acidification of the oceans

There are dangers associated with acidification of the oceans through the absorption of carbon dioxide (CO_2) from the atmosphere. Acidification is harmful to many marine ecosystems and there are potential negative consequences for fisheries and food supply. The global mean ocean surface is now more acidic than at any time in the last 25 million years.

climate system?



The overall message is that we have a greater understanding of many aspects of the climate system. The severity, timing and probability of the impacts are likely to depend on the pathway of future greenhouse gas emissions.

Tropical forest dieback

The Amazon rainforest and other tropical forests are vital biological reserves, and key components of the climate system. Observations show that these environments are vulnerable to extended drought, although climate models do not always correctly reproduce the mechanisms by which drought affects tropical forests. The impact of fire on forests is often still entirely overlooked in modelling simulations.

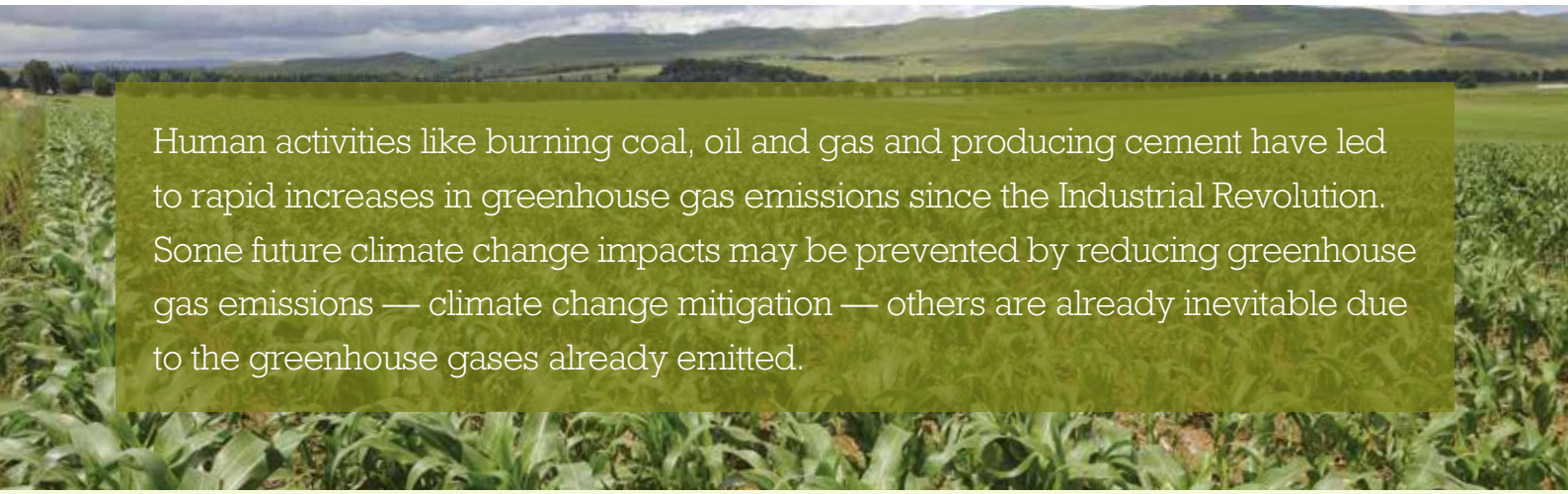
Carbon release from permafrost and ocean sediments

Stores of carbon are locked within permafrost and in ocean sediments. There is some observational evidence of thawing of permafrost, potentially leading to release of carbon into the atmosphere, and of methane escaping from the seabed into the ocean. Rising temperatures could increase the rate of release of these additional sources of greenhouse gases thus accelerating global warming. The likelihood, size and timescale of carbon release from permafrost and, especially, ocean hydrates are very uncertain.

Arctic sea-ice

Loss of Arctic sea-ice amplifies the amount of warming and may affect European weather. In September 2012, the sea-ice reached its smallest extent since systematic records began in 1979. Recent analysis that combines models and observations suggests that the Arctic may become largely ice free during most late summers this century. Some studies suggest the first occurence of this could be as early as 2025–2030.

What dangerous impacts can b



Human activities like burning coal, oil and gas and producing cement have led to rapid increases in greenhouse gas emissions since the Industrial Revolution. Some future climate change impacts may be prevented by reducing greenhouse gas emissions — climate change mitigation — others are already inevitable due to the greenhouse gases already emitted.

The AVOID programme explored the impacts avoided by introducing climate change mitigation policies that move from a pathway leading to a global average warming of 4 °C to one that limits warming to 2 °C by 2100. The benefits of mitigation are clear in most of the sectors studied (e.g. water, river flooding, coastal effects, agriculture, soil and infrastructure).

Where impacts are not avoided altogether, a key finding from AVOID is that climate change mitigation policies can delay some impacts by several decades, potentially allowing more time to prepare adaptation measures. Taking mitigating action also reduces beneficial impacts of climate change (e.g. longer growing seasons in some countries), but on a global scale the advantages of preventing the harms far outweigh the disadvantages of reducing the benefits.

The pathway leading towards 4 °C at 2100 is likely to result in significant impacts even by mid-century. The table below shows some plausible global climate change impacts in 2050. These have been derived from climate and impact models assuming a scenario with greater emissions than present day in which atmospheric concentrations of greenhouse gases continue to rise throughout the century. Estimates of impacts remain uncertain and these values should not be considered the most likely impacts of climate change.

SRES A1B scenario: plausible aggregated global scale climate change impacts in 2050.

People exposed to increased risk of water stress	975,000,000
People exposed to increased risk of river flooding	335,000,000
Additional people flooded per year by coastal flooding (assuming upgraded defences)	69,000
Increase in residential cooling energy demand	Up 55%
Change in global average spring wheat yield (including direct CO_2 carbon fertilisation effect)	Down 18%

e avoided by limiting warming?

A key AVOID study found that climate mitigation policies which achieve the 2 °C target reduce impacts by 20–65% by 2100 compared to the impacts in a world that reaches 4 °C.

Impacts AVOIDED

Figure 1 shows a plausible estimate of the impacts avoided for six key sectors by limiting global average warming to 2°C or 2.5 °C compared to a 'business as usual' pathway of 4 °C. The results include the fact that many impacts change in a non-linear way with climate change. When the climate change patterns from a wide range of climate models are considered, it becomes clear that the uncertainties in estimating climate impacts remain large — in some cases, the highest estimate may be 10 times bigger than the lowest.

In addition to the impacts shown in Figure 1, AVOID results also show that mitigation can reduce the negative impacts of climate change on biodiversity and reduce the loss of mountain glaciers, which are important for water supply in some parts of the world.

Although moving from a pathway that leads to 4 °C to one that leads to 2 °C can avoid some impacts, it will not avoid all undesirable effects. For those impacts still encountered, mitigating action may provide the benefit of more time to adapt.

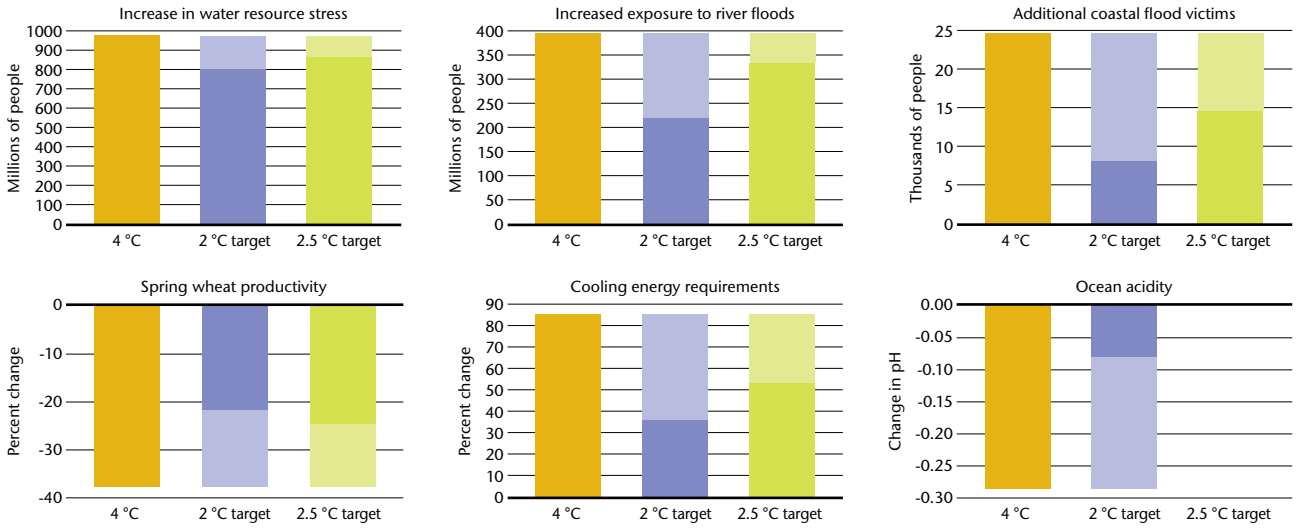
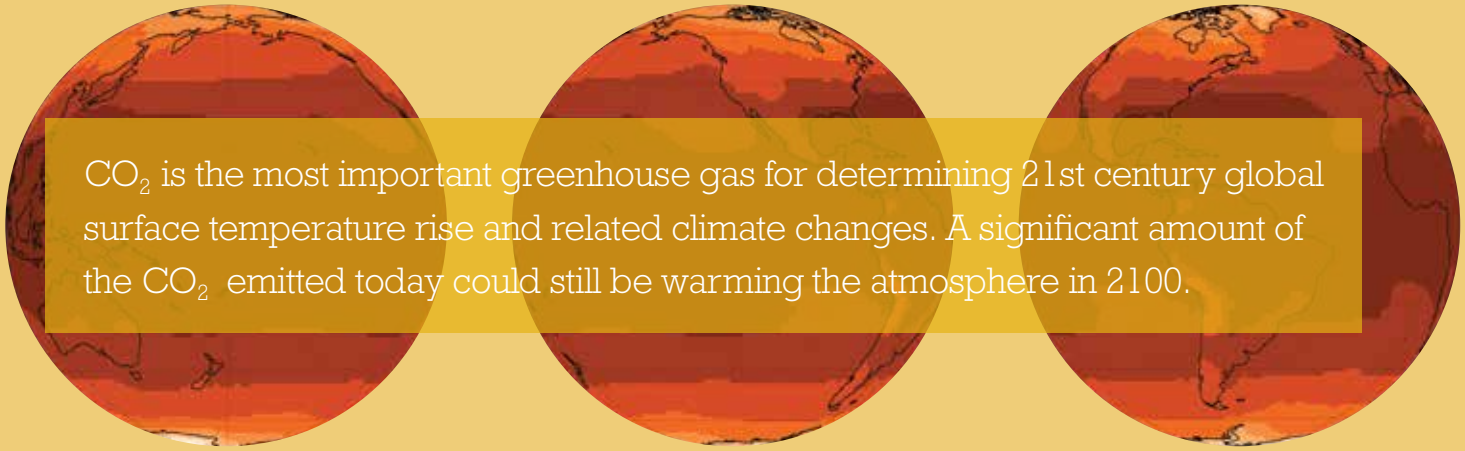


Figure 1: Plausible impacts avoided for six key sectors at 2100. The darker shading represents the projection of impacts for each pathway. The lighter shading for the 2 °C and 2.5 °C targets illustrates the avoided impacts compared to the 4 °C target.

What future emissions pathway will avoid dangerous climate c



CO_2 is the most important greenhouse gas for determining 21st century global surface temperature rise and related climate changes. A significant amount of the CO_2 emitted today could still be warming the atmosphere in 2100.

In 2011, the combined activities of just four regions — the European Union, United States of America, China and India — accounted for more than half of global CO_2 emissions. By 2012, global CO_2 emissions from burning fossil fuels and producing cement were about 60% higher than they were in 1990.

Looking to the future, the AVOID programme has calculated the climate consequences up to the end of the century and beyond of more than 100,000 greenhouse gas and aerosol emissions pathways. It also examined the probability of meeting different warming levels above pre-industrial temperatures.

Some of these pathways included prospective enhanced carbon removal, often called negative emissions technology. One example of this is bio-energy, along with carbon capture and storage. However, there is a significant amount of uncertainty about whether these innovations can be implemented on a large commercial scale and what the consequences for other land uses, such as food production, would be.

Three example pathways are shown below in Figure 2. These all limit warming to 2 °C above pre-industrial levels with at least 50% probability. For example, the orange line shows emissions peaking in 2020 before reducing at a rate of 3.6% per year and ultimately bottoming out at a negative emissions rate of 11 gigatonnes of carbon dioxide ($GtCO_2$) equivalent per year (eq/yr).

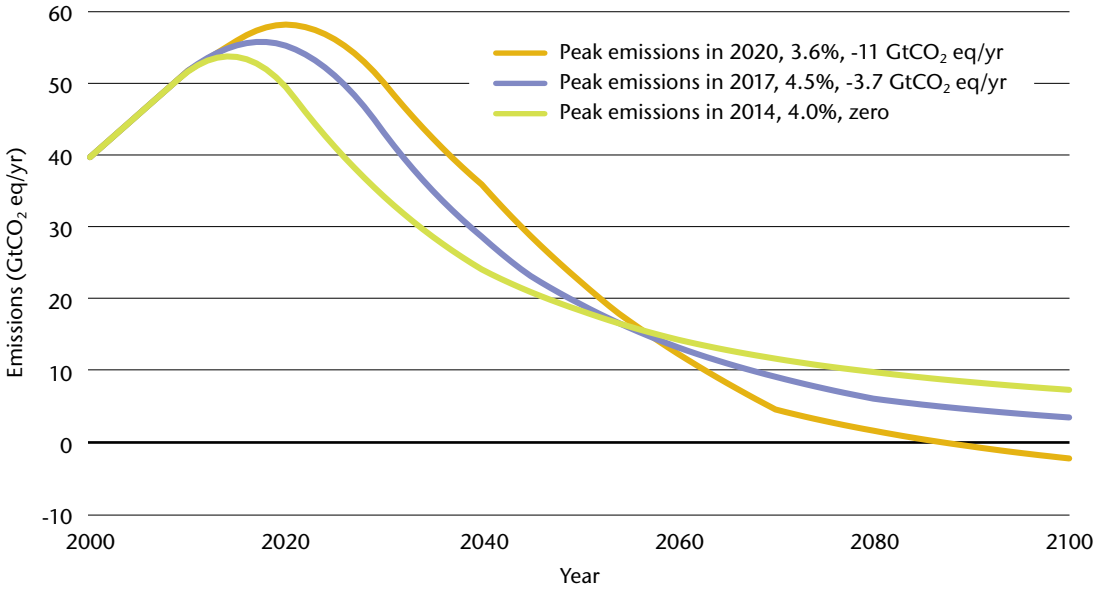


Figure 2: Examples of pathways that limit warming to 2 °C with at least 50% probability.

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change?

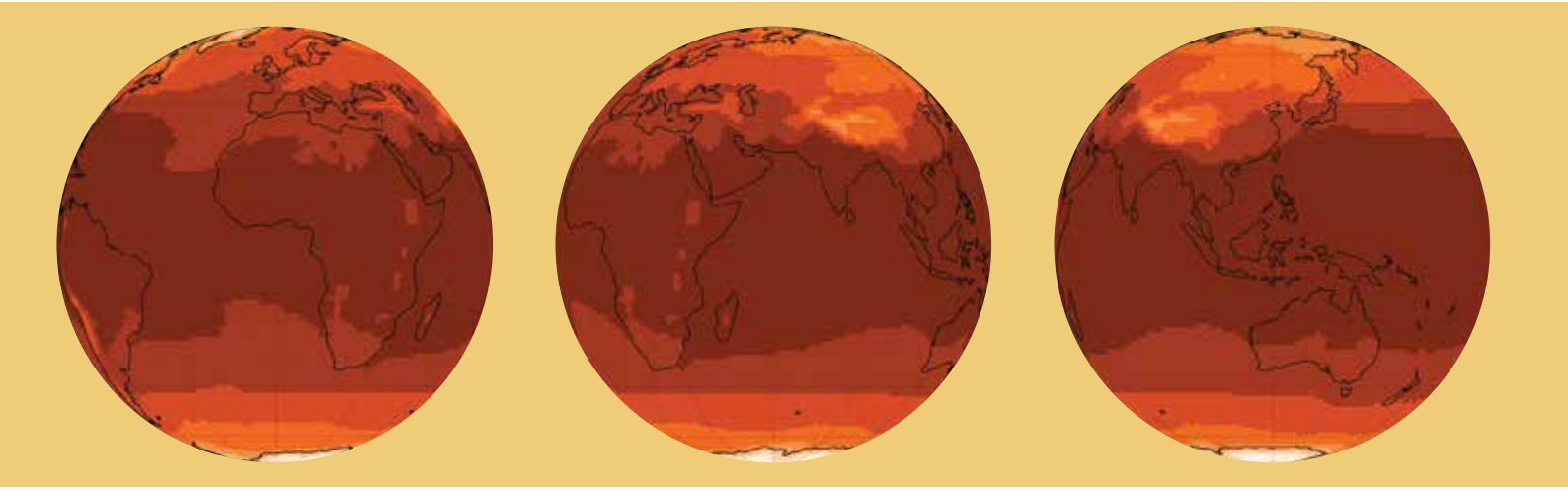


Figure 3 summarises the results of a number of emissions pathways that limit global warming to about 2 °C above pre-industrial levels with a 50% probability. The horizontal axis indicates the year emissions start to fall (peak year) and the vertical axis shows the subsequent annual rate at which emissions reduce. Blue dots do not include enhanced carbon removal. The different coloured dots show pathways that include varying amounts of CO_2 removal.

Keeping emissions on a pathway able to limit global warming to 2 °C above pre-industrial levels with at least a 50% chance, is seen as theoretically feasible but challenging. This will require rapid and sustained reductions in greenhouse gas emissions and some reliance on technologies that are not yet proven on a large scale.

This action would also reduce the chance of exceeding higher, more dangerous, global surface temperatures. For instance, Figure 4 shows the probability of more than a 3 °C rise is reduced to less than 10%, and a 4 °C rise is reduced to less than about 1%. This is important because, although we can't precisely map the probability of large-scale climate system change (e.g. the rapid deglaciation of the Greenland ice-sheet) or particular climate impacts to precise temperatures, there is strong evidence that the odds of these undesirable effects increase with temperature.

AVOID found that limiting warming to a more stringent level of around 1.5 °C could only be achieved by designing a global emissions pathway at the absolute extremes of what is currently considered feasible. Studies elsewhere confirm that limiting warming to below 1.5 °C in 2100 may involve a temporary temperature overshoot during this century.

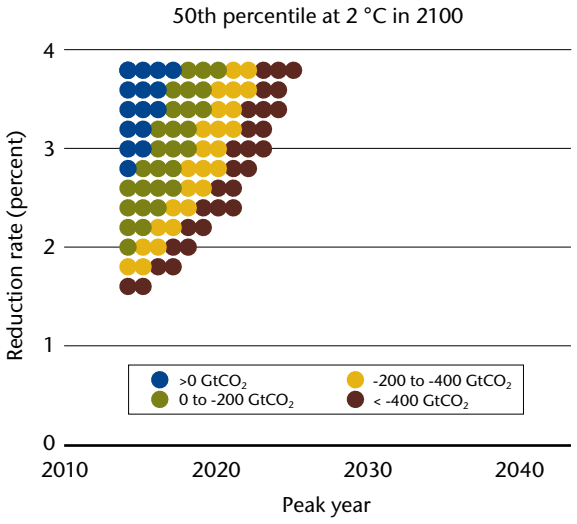


Figure 3: The peak emissions year and long-term reduction rate needed to have a 50% chance of keeping warming below the 2 °C limit. The colour of the dots represent the total amount of enhanced CO_2 removal.

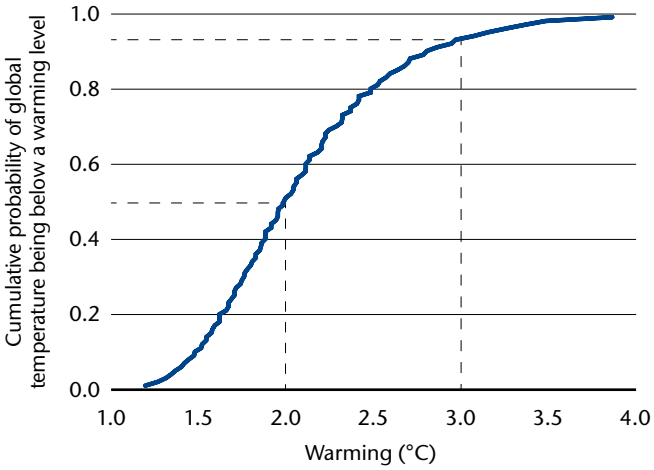


Figure 4: The probabilities of limiting warming to different levels following an emissions pathway with a 50% chance of limiting warming to 2 °C.

Which global emissions pathways are feasible?

The feasibility of low carbon pathways depends on the sensitivity of the climate, the ability of socio-economic systems to change and the deployment of mitigation technology.

The year by which emissions need to peak for a 50% chance of limiting global temperature rise to a range of different temperature limits above pre-industrial levels in this century are shown below in Figure 5. It shows four example temperature goals with and without enhanced CO_2 removal and assumes a long-term emissions reduction rate of 3% per year. Enhanced CO_2 removal delays the year in which emissions would need to peak. AVOID could not find a pathway with a 50% chance of limiting warming to approximately 1.5 °C without the enhanced removal of CO_2 or a temperature overshoot.

AVOID studies have also assessed the global and regional technology options and costs associated with long-term low-carbon pathways. Many of these studies use Integrated Assessment Model (IAM) results — a type of model that attempts to simulate economics, energy systems, technology development and climate.

Inter-model comparison of IAMs show that the transition to a global low-carbon economy needs to be well under way by 2050 in order to achieve an eventual 2 °C limit. Many transition pathways feature a mixture of renewable energy generation, nuclear power and carbon capture and storage applied to remaining fossil fuel emissions.

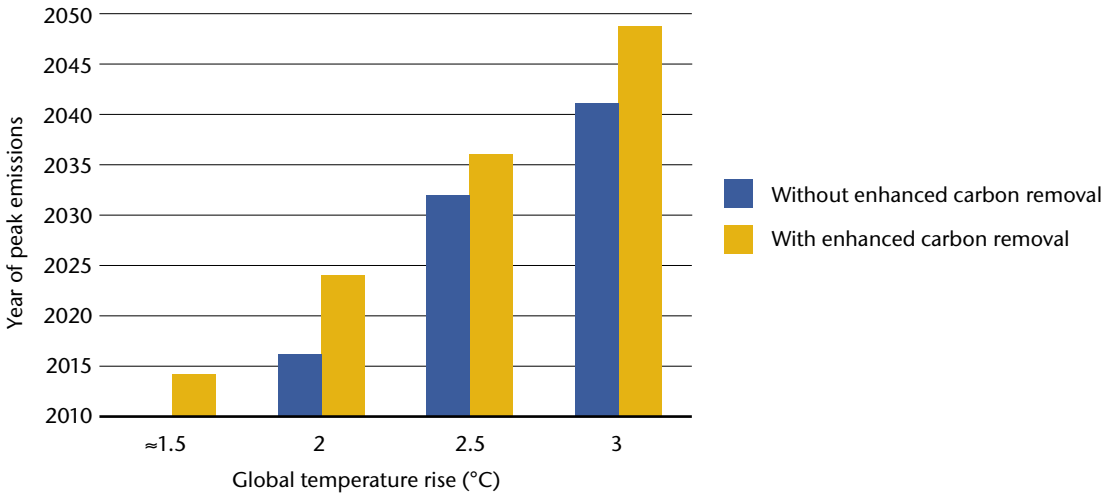
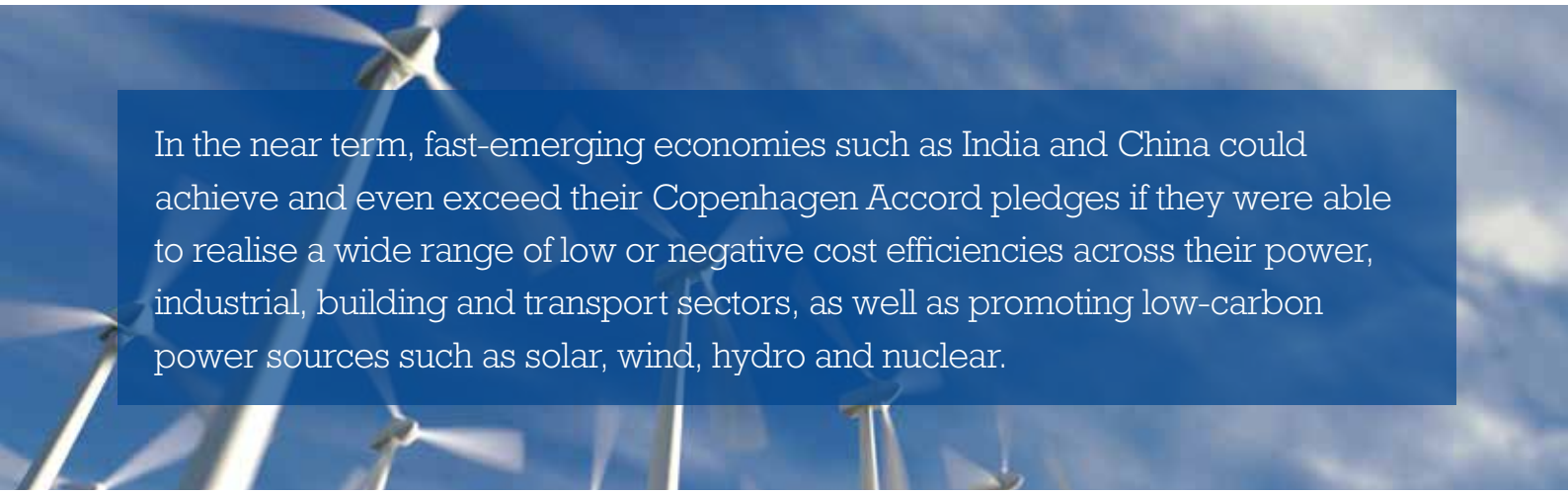


Figure 5: The years by which emissions need to peak for a 50% chance of limiting global temperature rise to a range of targets.

What is feasible at the regional level?



In the near term, fast-emerging economies such as India and China could achieve and even exceed their Copenhagen Accord pledges if they were able to realise a wide range of low or negative cost efficiencies across their power, industrial, building and transport sectors, as well as promoting low-carbon power sources such as solar, wind, hydro and nuclear.

China's Copenhagen Accord pledge is to reduce its CO_2 emissions per unit of economic output by 40–45% by 2020, compared to 2005 levels. Figure 6 outlines the potential major emissions savings in the Chinese economy by 2050, comparing an unmitigated baseline case with a low-carbon case which takes China to a very low level of CO_2 emissions in 2050. The biggest contributions come from savings in the electricity used in the industry and building sectors. A smaller, but still significant contribution is provided by the transport sector.

India's Copenhagen Accord pledge is to lower its greenhouse gas emissions per unit of economic output by 20–25% by 2020, compared to 2005 levels. Figure 7 shows an example of transition for India. As in the case of China, the greatest contribution to emissions reductions potentially comes from electricity production, where coal-dominated generation is replaced by a mix of nuclear, renewables (principally wind and solar) and carbon capture and storage, including biomass, creating a net negative emissions electricity sector by 2040. The industry sector is also responsible for significant emissions reduction by replacing coal with gas for industrial process heating.

Here, emissions under the mitigation scenario are shown in the dark-shaded colours. Total unmitigated emissions are shown by adding the pale and dark-shaded colours, hence the savings made by mitigation are shown in the light-shaded colours. Individual sectors are shown by different colours, as named in the key.

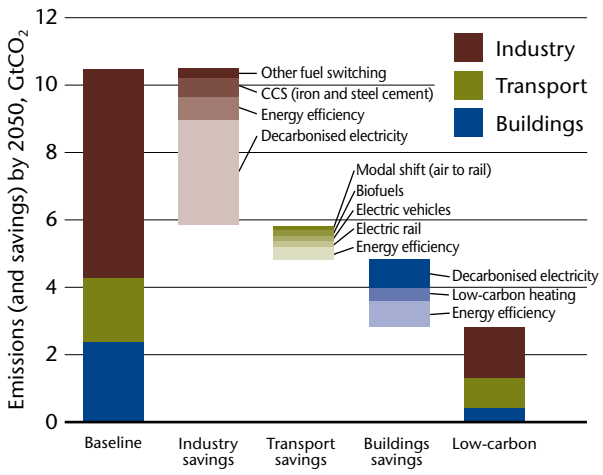


Figure 6: Emissions savings in China's energy end-use sectors by 2050, compared to a baseline case.

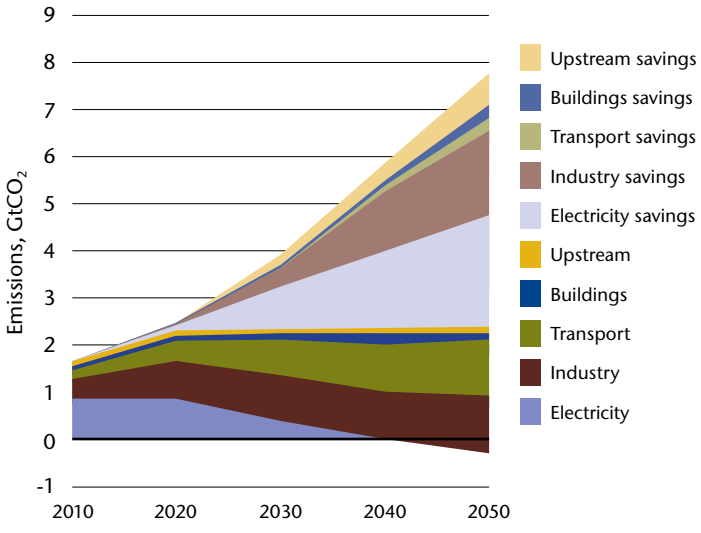


Figure 7: Example of transition to a low-carbon pathway for India to 2050.

AVOID is an accredited LWEC activity.

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